Architecture for Ultra-Large-Scale (ULS) Systems

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March 6, 2008

Software Engineering Institute | Carnegie Mellon

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U.S. Department of Defense

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
06 MAR 2008		**00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Architecture for Ultra-Large-Scale (ULS) Systems	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Carnegie Mellon University ,Software Engineering Institute (SEI),Pittsburgh,PA,15213**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**11**	

Design Research Area – Architecture Principles

Theories and constructs from the field of economics can endow the notion of architecture with new meaning and consequently offer structuring principles for Ultra-Large-Scale Systems.

What Is a Software Architecture?

"The **software architecture** of a program or computing system is the structure or **structures of the system,** which comprise the software elements, the **externally visible properties** of those elements, and the **relationships among** them.* "

- Architecture is an abstraction; it is not about the details, but …
- it expresses sufficient detail to support appropriate analyses …
- vis-à-vis important (quality attribute) requirements and …
- appropriately constrains more detailed design and implementation.

** Bass, L.; Clements; P. & Kazman, R. Software Architecture in Practice, Second Edition. 2003.*

From the ULS Systems Study

"… beyond certain complexity thresholds, a traditional centralized engineering perspective is no longer adequate nor can it be the primary means by which ultra-complex systems are made real. *"

"Like cities, ULS systems will not simply be bigger systems: they will be interdependent webs of software intensive systems, people, policies, cultures, and economics. *"

** Northrop, Linda "Ultra-Large-Scale Systems: The Software Challenge of the Future" ,SEI / CMU, 2006.*

Hints from Market Design

"Traditional economics views markets as simply the confluence of supply and demand. A new field of economics, known as 'market design,' recognizes that well-functioning markets depend on detailed rules. …"

- Market designers try to understand these differences and the rules and procedures that make various kinds of markets work well or badly."
- Their aim is to know the workings and requirements of particular markets well enough to fix them when they're broken or to build markets from scratch when they're missing.* "

** Roth, Alvin, "The Art of Designing Markets", Harvard Business Review vol. 85(10) pg 118-126, 2007*.

Inspiration – Radio Spectrum Auction -1 *

Spectrum licenses (for use in wireless communication) were originally allocated on the basis of hearings by the FCC.

- procedure was time consuming; backlog developed
- switched to lotteries; winners could resell at high prices (winner of a license to run cellular telephones in Cape Cod sold it to Southwestern Bell for $41.5 million)

A previously unrecognized ***value proposition*** emerged

- generate revenue
- allocate efficiently
- generate public value
- encourage participate by small business, minorities, …

** Osborne, An Introduction to Game Theory, p. 300, 2004. and*
McMillan, J., "Selling Spectrum Rights", Journal of Economic Perspectives, vol 8(5) pg 145-162, 1994.

Inspiration – Radio Spectrum Auction -2

"***Elements***" are individuals, organizations and resources

- government
- license acquirers; "***properties***" include:
  - private value for license based on competition situation, value placed on bundles of licenses based on competitive strategy and previously acquired licenses
  - financial status
  - minority status
  - competitive situation
- game theorists (who want to put theories to practical use; the most recent Nobel Prize in economics was awarded for Mechanism Design)
- resources

Inspiration – Radio Spectrum Auction -3

Problem type

- resource allocation
- resource to be allocated
  - —intervals of radio spectrum
  - —geographic regions

"***Relations***" are interaction protocols defined by mechanism, alternatives considered

- open vs. closed bidding
- first vs. second price auction
- sequential vs. simultaneous (allowing for license combinations)

Potential protocol "***properties***" (from game theory and mechanism design)

- Bayes-Nash equilibria
- incentive compatibility

Observations -1

Value proposition drives auction (and more generally) mechanism design

Value proposition and mechanism rules are at times learned and at times explicitly designed resulting in an interacting hierarchy of mechanisms *

- FCC policy
- Auction mechanism
- Cell phone system

Very different expertise is required for different levels of the hierarchy likely requiring different types of "architects" – the notion of a single central architecture team is "broken".

**Aoki, M., Toward a Comparative Institutional Analysis, 2001.*

Observations -2

Economic theories

- exploit rational self-interest and scale – a natural fit for ULS systems
- inform system structure in much the same as quality attribute theories inform software architecture structure

Theories are not perfectly matched to the situations they model

- must rely on combination of theory, experiments, and experience *
- ULS system architecture must support this **

Theories from other diverse disciplines such as biology, organizational learning, and sociology are also likely to offer ULS system structuring principles.

** Osborne, An Introduction to Game Theory, p. 300, 2004.*
*** Conversation with Kevin Sullivan.*

What Is a ULS System Architecture?

How about this?

The **architecture** of a ULS system is dynamic hierarchy / constellation of interacting system architectures, each with its own value propositions, element types (including individuals and organization) and associated properties (such as self-interest and private values), relations (such as those found in strategic games) and theories (such as game theory).

SEI ULS systems architecture research:

- Explore the nature of existing hierarchies / constellations
- Discover styles of ULS system architectures
- Continue exploring applicability of economic mechanisms
- Explore interaction between non-computational and computational mechanisms
- Explore institution design (Aoki)
- Explore theories from other disciplines